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Review

Cost Estimates and Policy Challenges of Transporting Renewable Energy Derived Ammonia from Gujarat, India to Japan

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Abstract: With growing concern about risks related to energy security around the world, the development of hydrogen cooperation between India and Japan has become very important to ensure the economic security of the two countries and to deepen economic cooperation. This study visualizes the costs and economic issues involved in transporting Ammonia from India to Japan and discusses the policy support needed to establish a hydrogen supply chain between the two countries. If Hydrogen production is conducted in Gujarat and Ammonia production is conducted using Haber–Bosch at a large-scale Ammonia plant, the price of Ammonia at the port of Tokyo can be reduced to 572 USD/mt-NH^3 if highly competitive renewable energy is utilized. For evaluating the characteristics of Ammonia produced in India, high contribution to greenhouse gas reduction, low transportation risk along transportation routes, and contribution to the diversification of energy procurement in Japan should be evaluated economically, and the following five initiatives will accelerate the composition of a Hydrogen value chain between India and Japan: (1) increasing the Indian governmental support for subsidies for Hydrogen production, (2) increasing financial support to lower capital costs, (3) ensuring a business environment to lower uncertainty about future costs, (4) promoting efforts to visualize the value of carbon credits such as JCM, and (5) visualizing the value of diversification of energy procurement sources for Japan. A graphical abstract is to follow.

Keywords: hydrogen; hydrogen policy; energy policy; India–Japan relationship

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1. Introduction

Hydrogen is being researched and developed around the world as a technology that reduces greenhouse gas (GHG) emissions and improves the flexibility of the entire energy system because of its characteristics that enable load shifting of fluctuating renewable energy generation and utilization of low-carbon energy in areas and time periods where it has been difficult to utilize renewable energy [1,2]. Japan formulated the world's first national Hydrogen strategy, the Basic Strategy for Hydrogen, in 2017, and hosted the Hydrogen Energy Ministerial Meeting (HEM) in 2018, continuing its contribution to the utilization of Hydrogen in the world [3]. After the formulation of the Basic Strategy for Hydrogen, Japan formulated the Sixth Basic Energy Plan, which stipulates that hydrogen and Ammonia will account for about 1% of the power supply mix in FY2030, positioning Hydrogen and Ammonia from a new energy source for the future to an energy source that will also play a part in the power supply [4]. For Japan to achieve carbon neutrality by 2050, the Basic Hydrogen Strategy has been revised as a guideline to clarify the recognition of issues and the policy for initiatives, while providing a common vision between the government and the private sector, showing a strong commitment to the early creation of a Hydrogen society. In this new strategy, Japan reaffirms its goal of introducing up to 3 million tons of Hydrogen per year in 2030 and about 20 million tons of Hydrogen per year in 2050. The meeting also set a target of 12 million tons per year for the introduction of Hydrogen by 2040 and presented specific policies for efforts toward the establishment of a global Hydrogen supply chain and the promotion of development to stimulate demand for Hydrogen. In addition, in establishing a Hydrogen value chain, the Japanese government has emphasized the importance of expanding demand in Japan and securing stable supply routes from overseas and will actively procure Hydrogen from outside of Japan. They have also begun discussions on preparing a specific incentive system to promote the procurement of Hydrogen from overseas. In particular, it has been specified that a scheme will be established to provide long-term support for operators, who plan to start supplying Hydrogen and Ammonia as first runners, by providing a subsidy which fills the price gap between the price of Hydrogen and Ammonia from overseas and the parity price of the existing fuel [5].

As the most recent discussion, the Japanese government announced its policy to achieve "Green Transformation" in August 2023, in which the government will issue 20 trillion JPY of green bonds and take measures to promote investment by the private sector, thus bringing a total of 150 trillion JPY (=1.15 trillion USD) in government and private sector investment to the area to achieve a realistic energy transition. Hydrogen is positioned as an essential technology for Japan to create a realistic energy transition. The policy also states that the Japanese government budget for FY2024 will provide the necessary funds for the establishment of a Hydrogen and Ammonia supply chain [6].

India, which is actively introducing Hydrogen technology and has highly competitive renewable energy power generation potential, could be an important partner for Japan in contributing to the establishment of a global Hydrogen value chain. The two countries have similar interests in Hydrogen technology, and synergies can be expected through mutual technological cooperation [7]. Currently, while there are existing studies on the economic evaluation of Hydrogen imported by Japan from regions such as ASEAN, the U.S., and the Middle East, there are no existing studies that have focused on regions with high potential for hydrogen production, especially from India. This study deepens the economics of transporting Hydrogen from India to Japan, which could be one of the key elements for Japan and India to establish a global Hydrogen value chain. Specifically, this study visualizes the challenges in establishing a supply chain between India and Japan for the transportation of Hydrogen produced in India from renewable energy sources to Japan, by finding: (1) an overview of the practical supply chain based on current regulations and policy measures and (2) the cost of establishing a supply chain and identifies the challenges for establishing a supply chain from India to Japan.

In order to visualize the reference price of Hydrogen from India to Japan, this paper provides a discussion of the most expected value chain for transporting Hydrogen from India to Japan and makes assumptions regarding the price of Hydrogen if this value chain is established. Section 2 discusses particularly promising Hydrogen production methods, Hydrogen production locations in India, and Hydrogen transportation pathways. Section 3 then examines the cost of Hydrogen production in India and the cost of converting it to Ammonia, a promising carrier of Hydrogen, and transporting it to Japan. In Section 4, based on the results obtained in Section 3, the price of Ammonia arriving in Japan will be verified, and Section 5, based on these results, identifies challenges in transporting Hydrogen from India to Japan and necessary future measures are discussed.

2. Assumptions for a Practical Hydrogen Supply Chain between India and Japan

2.1. Assumptions Regarding Hydrogen Production Methods

With regard to Hydrogen production methods, of the 95 million tons of Hydrogen produced worldwide in 2022, 83.5 percent is produced by reforming fossil fuels into gas and extracting Hydrogen from the gas. Hydrogen produced by introducing Carbon Capture, Usage and Storage (CCUS) technology into the reforming process, a method that is expected to reduce Carbon Dioxide (CO_2) emissions, and accounts for 0.6% of the total production and only 0.1% of the Hydrogen produced from electricity [8]. Thus, at present, reforming fossil fuels to produce Hydrogen is the most mature method of Hydrogen production in the world. A previous study on the economics of imported Hydrogen has studied hydrogen supply chains in the Asia Pacific Economic Cooperation (APEC) region and included countries such as the United States, Australia, and Indonesia, which can produce Hydrogen from fossil fuels. The analysis was conducted on both fossil fuel-derived and renewable energy-derived Hydrogen [9].

On the other hand, India is a fossil fuel-importing country that depends on imports from abroad for 75% of the Crude Oil consumed in the country as of 2019, and there is little incentive to produce fossil fuel-derived Hydrogen in India and export it abroad [10]. In addition, the Indian government announced a Hydrogen promotion policy, "National Green Hydrogen Mission", which essentially focuses on Hydrogen production from renewable energy sources [11]. Based on these discussions, it is assumed in this study that Hydrogen in India will be derived from renewable energy sources with respect to the production method.

2.2. Assumption of Hydrogen Production Point

Regarding the Hydrogen production sites, the study should be conducted in selected states where wind and solar power generation is being introduced because the price of electricity has a very strong influence on the activity of investment in Hydrogen [12]. Promising ports should be located for stable transportation of Hydrogen. In view of the renewable energy potential and actual deployment, Gujarat, Maharashtra, Rajasthan, Karnataka, and Andhra Pradesh are the most promising states [7]. Among these, Gujarat is the state with the highest energy consumption in India, especially in terms of oil and electricity, and thus has a high potential demand for Hydrogen with energy storage capabilities and the largest refinery owned by a private company located in India [10]. In addition, regarding the availability of ports that can serve as hubs for Hydrogen, the Indian government has submitted a Green Port Policy, which is beginning to designate priority ports in India where the use of renewable energy is being intensively promoted. Among the priority ports, the port of Kandla, located in Gujarat, is treated as a particularly important hub, and more central government support for infrastructure development is expected in the future [13]. Based on these considerations, this study focuses on a case in which Hydrogen produced from electricity derived from renewable energy sources generated in Gujarat is transported to Japan.

2.3. Assumption of Hydrogen Carriers

New technologies for Hydrogen storage and transport are still being developed and many possibilities are being explored. For example, a study published in 2022 reviewing the latest technologies for Hydrogen storage and transport identified Compressed Hydrogen, Liquid State, Cryogenic Compress, Solid Storage, Ammonia, and Liquid Organic Hydrogen carriers were listed as candidates for Hydrogen carriers [14]. On the other hand, the Energy Technology Perspectives 2023, issued by the IEA, describes liquid Hydrogen, Ammonia, and Liquid Organic Hydrogen Carriers (LOHCs) like Methylcyclohexane as realistic ways of shipping Hydrogen in 2030 [15]. Similarly, the International Renewable Energy Agency (IRENA) has produced a report on Hydrogen that focuses on three similar options for Hydrogen carriers in 2023, when transportation is assumed [16]. There is also a study published in 2022 that shows that Ammonia is also the cheapest option as a carrier to transport Hydrogen produced in Australia [17]. When considering long-distance marine transport of Hydrogen by ship, liquefied Hydrogen transport, the organic chemical hydrate method, or transport as Ammonia have been considered as the de facto options for a long time [18].

Toluene, which is used in the organic chemical hydrate process, and Ammonia can be transported by existing chemical tankers or liquefied gas carriers, respectively, and regulations and standards for carriers are well established [15]. On the other hand, there are no corresponding regulations for the transport of liquefied Hydrogen, and the development of these regulations is essential for the transport of liquefied Hydrogen from India to Japan. Liquefied Hydrogen is a type of liquefied gas, and its transport by sea is required by the International Code of the Construction and Equipment of Ships in Bulk (IGC Code) issued by the International Maritime Organization (IMO). However, the current IGC Code does not cover liquefied Hydrogen. Against this background, the IMO has issued a provisional recommendation for the carriage of liquefied Hydrogen in bulk. In the case of actual transportation of liquefied Hydrogen from India to Japan, the flag state of the vessel involved in the transportation and the port authorities of India and Japan, where cargo handling will take place, should conclude a trilateral agreement based on a provisional assessment and establish appropriate preliminary conditions of carriage in accordance with the principles of the Code. The carriage of liquefied Hydrogen between specified ports may be possible by establishing appropriate preliminary conditions of carriage in accordance with the principles of the Regulations [19]. Therefore, if the transportation of liquefied Hydrogen between India and Japan is to be oriented, it is expected to face not only technical and economic challenges but also institutional challenges, which will necessitate additional time to start transporting Hydrogen.

Unlike other carriers facing technical and institutional challenges, the number of projects to transport Hydrogen using Ammonia as a carrier has been steadily accumulating. In fact, in its 2022 report, the International Energy Agency (IEA) reported that most export-oriented hydrogen projects announced to the public in the two years prior to 2022 selected Ammonia as the Hydrogen carrier. The IEA, as well as other previous studies studying the economics of the Hydrogen supply chain, have argued for the superiority of Ammonia as a Hydrogen carrier [20–23]. When liquid Hydrogen, LOHC, and Ammonia are compared as Hydrogen carrier options in light of the long range from India to Japan, approximately 13,000 km, estimates show that they are the least expensive transport options in the 2030 cross-section. [15]. Furthermore, a report by NITI Aayog, a policy body of the Indian government, also assumes that Ammonia will be the main hydrogen carrier for Hydrogen for export [24]. Considering these factors, this study will focus on analyzing the case of Ammonia transportation as the most expected form of Hydrogen transportation in the near future.

3. Assumptions in Calculating the Cost of Ammonia Produced in India

The cost of Ammonia supply arriving in Japan is calculated as "Price of Ammonia arriving in Japan (Cost and Freight) = Free on-board price (price of shipment from production site) + transportation cost", and analysis is conducted for each of the prices of Ammonia at the production site and the transportation cost.

3.1. Assumptions Related to Cost Calculations for Hydrogen Production

Although research and development of new technologies for water electrolyzers are continuing around the world, by the end of FY2022, 700 MW of electrolyzers had been installed worldwide, 60% of which are alkaline electrolyzers and 30% are Polymer Electrolyte Membrane (PEM) electrolyzers [8]. In 2023, China installed a large number of alkaline electrolyzers, but PEMs have the ability to convert renewable energy fluctuations into Hydrogen more efficiently and are expected to be installed more frequently in the future [8,25]. Regarding the cost of the water electrolysis system, since it is assumed that in the future as much renewable energy as possible will be converted to Hydrogen and transported to Japan, the cost will be estimated based on the assumption that the PEM, which has the highest Hydrogen production efficiency among the currently established technologies, will be introduced [26]. Regarding foreign exchange and financing costs, previous studies estimating Hydrogen transportation costs from the APEC region have studied costs with a fixed value of 5% discount rate, 1.4% tax rate, 15-year depreciation period, and 100% equity ratio [9]. In this study, the following assumptions were made to set values that are as realistic as possible in India's recent business environment.

(1) Depreciation period: The depreciation period is assumed to be 15 years, which is the typical depreciation period for plants in India [27].
(2) Equity ratio: The capital adequacy ratio is assumed to be 60%, which is the upper limit of the loan ratio under the standard loan terms and conditions of the Japan Bank

for International Cooperation (JBIC), and the interest rate is set at 3%, assuming a foreign currency premium and a minimum risk premium on top of the standard loan rate [28].

(3) Equity Internal Rate of Return (EIRR): The EIRR value is assumed to be 9%, following the analysis conducted by the Ministry of Economy, Trade and Industry of Japan (METI) on fuel Ammonia [29].

(4) Inflation rate: For the inflation rate, we assume 4.54%, which is the weighted average of the 2017–2022 inflation rate in India [30].

(5) Tax rate: The tax rate is set at 5%, assuming that the same tax rate as for general gas and biogas will be set in the future [31].

(6) Exchange rate: For the exchange rate from USD to INR, 1 USD = INR 80 is applied, which is the average value for FY2022 [32].

(7) Costs associated with water electrolysis equipment: The model of the Department of Energy, The United States of America (DoE) is used to calculate the costs associated with the production of hydrogen. Therefore, following the model's main assumptions, a production capacity of 530 tons of H^2 per year, an electricity consumption intensity of 55.8 kWh/kg H^2, a service life of 20 years, and a Total Uninstalled Capital (2016$/kW) value of 599 USD have been used [33].

(8) Electricity prices: In India, renewable energy capacity is growing rapidly, with both the central and state governments providing incentives, especially for solar PV capacity expansion. As of May 2022, 160 GW of capacity has been installed and will continue to expand [34]. In this study, the price of Hydrogen produced entirely from renewable energy sources will be studied. It is assumed that the cost of electricity input to the water electrolysis system is equivalent to the cost of renewable energy generation. The following two assumptions are made regarding the cost of electricity, which has the greatest impact on the price of hydrogen production.

   (i) The case for using highly competitive renewable energy sources (Competitive case): The recent Gujarat Electricity Regulatory Commission (GERC) renewable energy buyback prices are INR 2.51 (=0.031 USD)/kWh for 860 MW of solar power as of May 2023 and INR 2.84 (=0.036 USD)/kWh for 500 MW of wind power as of December 2022 [35,36]. Referring to these prices and assuming half solar and half wind power, this study assumes an electricity tariff of INR 2.675 (=0.033 USD)/kWh.

   (ii) The case for using average price sources (average case): As a case using average electricity rates, this study refers to a general electricity purchase price of INR 5.22 (=0.065 USD)/kWh, as published by Paschim Gujarat Vij Company Ltd. which operate their business in Gujarat State, India [37].

3.2. Costs Related to Hydrogen Production

For the calculation of the Hydrogen price, the Hydrogen Production Cost from the PEM Electrolysis model published by the DoE was used as a reference [33]. Assuming conditions 3.1.(1) through 3.1.(8) and calculating costs based on the DOE model, the cost of producing Hydrogen is 2.72 USD/kg-H^2 in case 3.1.(8) (i) and 4.54 USD/kg-H^2 in case 3.1.(8) (ii).

The IEA report describes that electricity prices from renewable energy sources account for 25% to 40% of the hydrogen price. In addition, the lower limit of the price of Hydrogen produced from onshore wind and solar power is estimated to be approximately 4 USD/kg-H^2 in FY2022 [8]. The IRENA report estimates Hydrogen prices in 2020 in the range of 3 USD/kg-H2 to 4.5 USD/kg-H2 and this result is also close to the range of current estimates [38].

As factors to be noted that may affect the price to a certain degree, the land cost for the location where the water electrolysis-related facilities will be installed is not entered, and the engineer's cost refers to the value assumed for production in the United States. Other factors that should be noted that have little impact on the price are that the price of water required for Hydrogen production is assumed to be the price of water in the U.S. and that the price of waste is not entered. And, the cost of desalination is not included, which will not have much impact on the estimation since it will be a very small portion of the overall cost of Hydrogen production [25].

3.3. Costs Associated with the Conversion to Ammonia

Regarding the conversion to Ammonia, three patterns are considered in a previous study that analyzed the economics of Ammonia produced via a water electrolyzer and the Haber–Bosch process: a large plant (2000 mt (million tons)/day), a medium plant (545 mt/day), and a small plant (91 mt/day) [39]. Following the study's example, capital costs are assumed to be 34 USD for the large plant, 51 USD for the medium plant, and 66 USD for the small plant per mt-NH^3/day. In addition, O&M costs are assumed to be 13 USD for large plants, 36 USD for medium plants, and 77 USD for small plants. Table 1 summarizes the main assumptions from Sections 3.1–3.3.

Table 1. Main assumptions for calculating the cost of Ammonia.

Depreciation period	15 years	
Equity ratio	60%	
Interest Rate	3%	
EIRR	9%	
Inflation Rate	4.54%	
Tax Rate	5%	
Exchange Rate	1 USD = 80 INR = 130 JPY	
Capital Cost of Electrolyzer (Capacity: 530 mt-H^2/Year)	599 USD	
Electricity Cost	(i) Competitive case: 0.033 USD/kWh (ii) Average case: 0.065 USD/kWh	
Ammonia Plant Cost	Large (2000 mt/day)	
	Capital Cost: 34 USD	O&M Cost: 13 USD
	Medium (545 mt/day)	
	Capital Cost: 51 USD	O&M Cost: 36 USD
	Small (91 mt/day)	
	Capital Cost: 66 USD	O&M Cost: 77 USD

3.4. Cost of Transporting Ammonia

The cost of transporting Ammonia from India to Japan will be estimated by following the assumptions made by the Public–Private Task Force on Fuel Ammonia Supply Chain led by METI [29].

(1) Ship Type: The Very Large Gas Carrier (VLGC) is a vessel used to cool and liquefy cargo, and its tanks are made of a special steel material that can withstand low temperatures and are equipped with a special device called a re-liquefaction system to keep the temperature of the cargo below the boiling point at all times [40]. This study will follow the Task Force's approach and assume that the ship is 84,000 $m^3 \approx$ 55,000 mt-NH^3 and that the ship is priced at USD 88 million [29]. In addition, this study assumes the same values as the METI's task force as follows for the port charges, average speed of ships, fuel consumption during the voyage, fuel consumption during port calls, and fuel prices, since no significant differences are expected between hauling from India and hauling from other countries.
(2) Port charge at loading and unloading points: USD 50,000 for the port of loading and USD 60,000 for the port of unloading.
(3) Average speed: 16.5 knots.
(4) Fuel consumption (at sea) (heavy oil): 48 mt-Fuel Oil (FO)/day.
(5) Fuel consumption (in port) (heavy oil): 10 mt-FO/day.
(6) Fuel price (heavy oil): USD 530/mt-FO.

(7) Distance between the Kandla port to the Tokyo port: As for the transport distance from the Port of Kandla, Gujarat to the Port of Tokyo, it will be 6826 nm one way and a 13,652 nm round trip [41].

Calculating transportation costs based on assumptions from 3.4.(1) through 3.4.(7), the total time for the voyage is 36 days, considering the 5 days of anchorage required for refueling, and the total transportation cost is 43 USD/mt-NH^3. If the same calculation method is applied to the route from the port of Chennai, which is the port nearer to Tokyo than Kandla, the total transportation distance is 5628 nm one way and 11,256 nm round trip, and the total time required for the voyage is 35 days, and the total transportation cost is 36 USD/mt-NH^3 [42].

4. Cost of Ammonia upon Arrival in Japan

4.1. Competive Case and Average Case

For the price of Hydrogen, this study assumes a result of 2.72 USD/kg-H^2 in the competitive case of 3.1.(8) (i) and 4.54 USD/kg-H^2 in the average case of 3.1.(8) (ii). Theoretically, the mass composition of Ammonia (NH^3) is 177 kg of Hydrogen and 823 kg of Nitrogen [43]. Following this previous study, the electricity required to generate 7.09 tons of Nitrogen is 306 kWh, which means that the electricity required to generate 1 kg of Nitrogen is estimated to be 0.043 kWh. The assumptions in 3.1.(8) (i) are 0.033 USD/kWh for the competitive case and 0.065 USD/kWh for the average case. The costs, excluding equipment required for the conversion of Hydrogen and Nitrogen to Ammonia, are as follows.

(1) Competitive case (2.72 USD/kg-H^2): 1 ton of NH^3 = 481 USD + 0.043 kWh $\times$ 0.033 USD $\times$ 823 kg of N = 482 USD
(2) Average case (4.54 USD/kg-H^2): 1 ton of NH^3 = 804 USD + 0.043 kWh $\times$ 0.065 USD $\times$ 823 kg of N = 806 USD

For the conversion to Ammonia from Hydrogen, based on the results of Section 3.3, capital and O&M costs are 34 USD and 13 USD for large plants (2000 mt/day), 51 USD and 36 USD for medium plants (545 mt/day), and 66 USD and 77 USD for small plants (91 mt/day), respectively, per mt-NH^3.

Regarding the transportation cost, Section 3.4 shows that the cost would be 43 USD/mt-NH^3 if the cargo is transported from Kandla Port, Gujarat. If the environment for exporting is the Chennai port, which is closer to Japan than Kandla port, the transportation cost would be 36 USD/mt-NH^3.

Based on these assumptions, the price of Ammonia exported from India ranges in price from 565 USD/mt-NH^3 to 992 USD/mt-NH^3. The price of Hydrogen accounts for most of the price, and electricity prices have a strong influence on the price of Hydrogen. It also has a significant impact on the efficiency of Ammonia plants. The price was calculated to be 572 USD/mt-NH^3 in the best-case scenario of Ammonia export from the port of Kandla, which is assumed in this study. Table 2 shows the prices of the main factors in the competitive case (2.72 USD/kg-H^2).

Table 2. Main factors of the Ammonia arrival cost in Japan.

Electricity price	0.033 USD/kWh
Hydrogen price	2.72 USD/kg-H^2
Costs associated with hydrogen and nitrogen production	482 USD
Ammonia plant size	Large (2000 mt/day)
Capital cost for H-B plant and ASU unit (58% of full gas-based H-B plant)	34 USD
O&M expenses for H-B plant (58% of full gas-based H-B plant)	13 USD
Port	Kandla
Transportation	43 USD
Total (USD/mt-NH^3)	572 USD

4.2. Discussions

With regard to the import price of fossil fuel-derived Ammonia in Japan, there are previous studies showing that the cost of imports from Saudi Arabia is 131 USD/mt-NH^3, 301 USD/mt-NH^3 from China, and 338 USD/mt-NH^3 from the United States. And METI estimates that in 2022, Ammonia made from natural gas with CO_2 captured during production will be 339 USD/mt-NH^3 from the Middle East, 413 USD/mt-NH^3 from North America, and 429 USD/mt-NH^3 from Oceania in 2030 [20]. Considering the results in Section 4.1, the price of Ammonia from India is relatively expensive, even in the competitive case [44]. Therefore, even if the conditions of the average case are not met, there will be no price competitiveness for Hydrogen imported from India.

This study has already adopted a CAPEX price of 599 USD/kW for water electrolyzers, which is almost the same as the IEA's estimate of 600 USD/kW, the optimistic figure to be met in 2030, and it is difficult to realistically assume further price reductions [8]. In addition, the CAPEX cost assumes the maximum support that JBIC can provide, and it is not possible to assume a further price decline. Therefore, this estimation is already based on an optimistic scenario [28].

One factor that would make the price even lower than the competitive case is that in 2020, India recorded a price of INR1.99 (=0.025 USD)/kWh for solar energy, and it can be assumed that the price of renewable energy will be lower than 0.033 USD/kWh [45]. On the other hand, in the optimistic scenario, even if the price of Hydrogen delivered to Japan were to drop by 20% from the price estimated in Section 4.1, the price would not be competitive with Hydrogen delivered from the United States or the Middle East. Therefore, to facilitate hydrogen transportation between India and Japan, it is essential to reduce the price difference. To reduce the price gap, it is necessary to take both measures to lower the price and to add concrete evaluation value to the hidden value of Hydrogen from India that has not yet been identified.

5. Necessary Policy Support in Transporting Ammonia from India to Japan

5.1. Measures to Reduce the Price of Hydrogen

As analyzed in Section 4, various factors will affect the competitiveness of Ammonia produced in India until it is transported to Japan after Hydrogen is produced in India and converted to Ammonia. It will be important to accumulate measures to reduce prices and increase price predictability. The National Green Hydrogen Mission, announced in January 2023, outlines the Strategic Intervention for Green Hydrogen Transition (SIGHT) program with a budget of Rs. 174.9 billion (=14 billion USD) to provide different financial incentives for domestic production of water electrolysis equipment and Hydrogen production, respectively [11]. Subsequently, the Indian government announced a specific support measure: an incentive for Hydrogen production. The specific amount of the incentive is to be granted up to INR 50 (=0.625 USD)/kg-H^2 for the first year, INR 40 (=0.5 USD)/kg-H^2 for the second year, and INR 30 (=0.375)/kg-H^2 for the third year. Bidders must specify their annual production capacity of Hydrogen derived from renewable energy and the incentive amount (in INR per kilogram) they are seeking. Eligible bidders will be allocated production capacity based on the lowest average incentive amount requested in INR per kilogram [46,47]. This incentive for Hydrogen production is relatively weak compared to the incentive in the United States, which could be a competitor as a producer of Ammonia derived from renewable energy. In the "Hydrogen Shot" policy, launched in June 2021, the U.S. government announced a goal of 1 USD per kg of clean Hydrogen within 10 years [48]. And, to expand the use of Hydrogen in the industrial sector, the Inflation Reduction Act has put forth a 10-year tax credit for clean Hydrogen production, with a maximum credit of 3 USD/kg-H^2 [49]. In the initial phase, it is envisioned that the Indian government's strengthening of incentives for Hydrogen production to encourage the participation of private companies will be a very important factor in the early creation of Hydrogen transportation between the two countries.

Financial support also needs to be enhanced. Since Hydrogen production is a very capital-intensive project, it is estimated that if the capital cost increases from 5% to 10%, the final cost of hydrogen production will increase by 40% [8]. In this case, this study assumed a case in which JBIC's support was fully utilized, but the cost of capital in India is generally very high. A survey indicates that the average rate for equity financing is about 14% [50]. The cost of financing certainly affects the cost of Hydrogen production from renewable energy sources.

In addition to providing direct governmental support like subsidies and financing, visualizing peripheral costs and increasing the predictability of project costs will also contribute to the promotion of Hydrogen production in India. For example, the issue of securing land for a site is recognized as a challenge for Japanese companies to implement projects in India due to the difficulty of land expropriation. In fact, Japanese government think tanks, private think tanks, and industry associations have all identified this challenge as a difficult issue in implementing projects in India [51–53]. During the calculations based on the DoE model used for this estimation, land-expropriation cost has only a relatively small impact on the final price of Ammonia compared to the electricity price [33]. Rather than lowering the expropriation costs, it is expected that clear visibility of the site expropriation costs and increased predictability of the project, such as a guarantee by the government, would strongly encourage project implementation. In India's National Green Hydrogen Mission, the central government of India encourages the state governments to implement policies for the provision of land and water, suitable tax and duty structures, and other measures to facilitate the establishment of Hydrogen projects [11]. Prompt implementation of such initiatives by state governments would facilitate the implementation of Hydrogen projects.

5.2. Measures to Visualize Values That Have Not Been Visualized and to Add Concrete Evaluation

It is important to enable the trading of Ammonia derived from renewable energy sources produced in India with a specific price attached to its value. In particular, the aspects of contributing to the reduction of GHG emissions and improving Japan's energy security should be evaluated as important values, and it is necessary to create an environment in which trading can take place.

First, focusing on the low level of carbon intensity, the creation of a carbon credit system in a bilateral setting that specifically values the amount assessed for the GHG to be reduced will undoubtedly contribute to closing the price gap. The Joint Crediting Mechanism (JCM) is a system to quantitatively evaluate the GHG emission reductions and removals achieved through the diffusion of superior decarbonization technologies and other measures implemented in cooperating countries [54]. If the JCM scheme is concluded between India and Japan, it will provide an incentive for private companies that are willing to achieve carbon neutrality to implement Hydrogen projects in India, since the CO_2 reduced by Hydrogen-related technologies will be authorized. Currently, some companies are beginning to charge a price of about 150 USD per ton of CO_2 reduction, and the JCM scheme will make a strong contribution to justifying the implementation of hydrogen projects in India by private companies from an economically rational point of view [55]. Japan has been holding discussions on the JCM with the countries concerned since 2011 and has established the JCM with 27 countries as of July 2023. Although an aide-memoire was signed in New Delhi, India, in March 2023 between the Ministry of Environment of Japan and the Ministry of Environment, Forests and Climate Change of India confirming the intention to establish the JCM, the scheme has not yet come into effect [56]. The issuance of the JCM will not only visualize the economic value of GHG reductions but will also contribute to the technology transfer of Hydrogen-related technologies from Japan to India. The Japanese government has contributed subsidies for overseas demonstrations using JCM and is promoting the quantification of GHG emission reductions and absorption by technologies and systems that contribute to GHG reductions. This can generate benefits for both India and Japan that will facilitate the transfer of necessary Hydrogen technologies from Japan to India and create business opportunities in India [57].

METI has announced the creation of a support system focusing on the difference between the cost of supplying Hydrogen and Ammonia and the selling price to consumers, with the aim of enhancing investment predictability for suppliers and establishing a large-scale supply chain on a private basis. It is anticipated that this program will promote the importation of Hydrogen by providing the government with compensation for the difference between the cost of supplying Hydrogen and the price at which it is sold to consumers. In addition to the cost of supplying Hydrogen per unit volume, the requirements for projects eligible for this program include economic independence at the end of the support phase, safety of the supply chain from production to transportation, compliance with CO_2 emission thresholds (environmental friendliness), compliance with safety standards, and certainty of future business creation [58]. One of the crucial values of Ammonia produced in India is that it is derived from renewable energy sources and is less subject to price fluctuations caused by external factors than fossil fuels. In addition, the risks associated with transport routes, such as the Strait of Hormuz, are relatively low compared to transporting Ammonia from the Middle East. Energy that can be transported without passing through the Strait of Hormuz is highly valuable to Japan and should be considered as an evaluation factor in METI's proposed support program to promote Hydrogen imports [59]. In addition, the United States, the Middle East, and Australia, which are currently being considered as potential Hydrogen supplier countries, are all oil-producing countries, and new Hydrogen imports from these countries would not contribute to the diversification of Japan's energy procurement. Importing Hydrogen from India, which is not an oil-producing country, would contribute to the diversification of Japan's energy supply sources, and this point should be taken into consideration.

6. Conclusions

6.1. Learned from This Study

This study visualizes the costs and economic issues involved in transporting Ammonia from the state of Gujrat in India to Japan and discusses the necessary policy supports for establishing a Hydrogen supply chain between the two countries, based on the assumption that Ammonia is the most efficient carrier of Hydrogen given the current level of technology. If Hydrogen production is conducted in Gujarat, which is considered to have high potential for Hydrogen production in India, Ammonia production is conducted by Haber–Bosch at a large-scale Ammonia plant, and Ammonia is transported from the port of Kandla to Tokyo Bay, the price of Ammonia at the port of Tokyo can be reduced to 572 USD/mt-NH^3 if highly competitive renewable energy is utilized. In fact, the price of electricity to produce Hydrogen accounts for a large portion of this overall price, confirming once again that electricity prices have a very strong influence on the price of Hydrogen. The import price of Ammonia in Japan, which is derived from fossil fuels with CO_2 removed in the manufacturing process, was 339 USD/mt-NH^3 from the Middle East, 413 USD/mt-NH^3 from North America, and 429 USD/mt-NH^3 from Oceania in 2030, making the price of 572 USD/mt-NH^3 for Indian Ammonia relatively expensive (Table 3 shows this summary.).

Table 3. The price of Ammonia arrival in Japan.

Place of Origin	Price
The Middle East	339 USD/mt-NH^3
The United States	413 USD/mt-NH^3
Oceania	429 USD/mt-NH^3
Gujarat, India	572 USD/mt-NH^3

Efforts such as (1) increasing the Indian governmental support for subsidies for Hydrogen production, (2) increasing financial support to lower capital costs, (3) ensuring a business environment to lower uncertainty about future costs, (4) promoting efforts to visualize the value of carbon credits such as JCM, and (5) visualizing the value of diversification of energy procurement sources for Japan are necessary. Once these initiatives are carried out, the value of Hydrogen produced in India will be evaluated in monetary terms, and the possibility of competing with Hydrogen produced in other candidate countries will increase (Figure 1 shows this competitive structure with Hydrogen produced in other countries.).

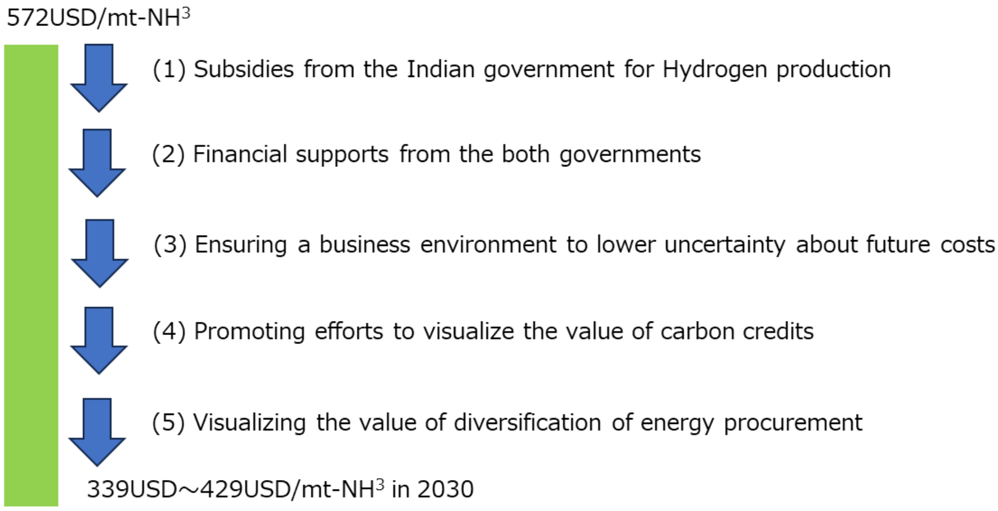

Figure 1. Competitive structure with Hydrogen produced in other countries.

6.2. Future Works

In the future, technological innovations are expected, especially in storage and transport technologies. As the IEA has estimated, the amount of Hydrogen transported by liquefied hydrogen will increase by 2030. Japanese companies are also developing ships that can transport liquefied Hydrogen, as well as fuel vehicles, Hydrogen turbines, and other technologies that require high-purity Hydrogen. Although, it is necessary to consider the legal issues faced when transporting Hydrogen from India using liquefied Hydrogen as a carrier, and the costs involved should be estimated in the future because it could be one of the prospective Hydrogen carriers [15,17,60–62].

Technological risk, which has a significant impact on prices, also needs to be reflected in the estimation method based on the results of future demonstration experiments around the world and the latest trends in technological development. This study assumed a case in which there is already a demonstration case, but it is necessary to appropriately reflect new technological risks that may arise in the phase of future large-scale production. In addition to this, with regard to PEM, the technology used for manufacturing, factors that may cause a large deviation from the current estimation include (1) the possibility of a significant model change and (2) the risk that if there is no development from the current technology, platinum-based precious metals such as iridium will be required as components, and the price will not fall easily [25,63]. Detailed mathematical estimates, including risk scenarios, should also be made as future technological trends become clearer.

Ammonia produced in India could be relatively expensive as of now compared with Hydrogen imported from other regions such as the U.S. However, Hydrogen from India is derived from renewable energy and thus has a high contribution to greenhouse gas (GHG) reduction. Also, Hydrogen has low transportation risk along transportation routes, and it contributes to the diversification of energy procurement in Japan. Research is needed to visualize the currently un-visualized value of Hydrogen imported from India. For example, If the positive impact of Indian Hydrogen on GHG reduction in Japan as a whole can be visualized, it is expected that the value of Hydrogen transported from India will be more appropriately evaluated.

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References

1. Otto, M.; Chagoya, K.L.; Blair, R.G.; Hick, S.M.; Kapat, J.S. Optimal Hydrogen Carrier: Holistic evaluation of hydrogen storage and transportation concepts for power generation, aviation, and Transportation. *J. Energy Storage* **2022**, *55*, 105714. [CrossRef]
2. Schrotenboer, A.H.; Veenstra, A.A.T.; uit het Broek, M.A.J.; Ursavas, E. A green hydrogen energy system: Optimal Control Strategies for integrated hydrogen storage and power generation with wind energy. *Renew. Sustain. Energy Rev.* **2022**, *168*, 112744. [CrossRef]
3. Ministry of Economy, Trade and Industry (METI). Basic Hydrogen Strategy. 2017. Available online: https://warp.da.ndl.go.jp/ (accessed on 14 September 2023).
4. Ministry of Economy, Trade and Industry (METI). The Sixth Basic Energy Plan. 2021. Available online: https://www.meti.go.jp/press/2021/10/20211022005/20211022005-1.pdf (accessed on 14 September 2023).
5. Ministry of Economy, Trade and Industry (METI). Basic Hydrogen Strategy. 2023. Available online: https://www.meti.go.jp/shingikai/enecho/shoene_shinene/suiso_seisaku/pdf/20230606_5.pdf (accessed on 14 September 2023).
6. Cabinet Secretariat of Japan (CAS). Toward the Realization of Green Transformation in Our Country. 2023. Available online: https://www.cas.go.jp/jp/seisaku/gx_jikkou_kaigi/dai7/siryou1.pdf (accessed on 14 September 2023).
7. Otaki, T.; Shaw, R. The potential of collaboration between India and Japan in the hydrogen sector. *Energies* **2023**, *16*, 3596. [CrossRef]
8. IEA. *Global Hydrogen Review 2023*; IEA: Paris, France, 2023; License: CC BY 4.0. Available online: https://www.iea.org/reports/global-hydrogen-review-2023 (accessed on 14 November 2023).
9. Kan, S.; Shibata, Y. Evaluation of the Economics of CO_2 Free Hydrogen Supply in the APEC Region. 2019. Available online: https://www.jstage.jst.go.jp/article/jjser/40/1/40_1/_article/-char/ja/ (accessed on 14 September 2023).
10. IEA. *India Energy Outlook 2021*; IEA: Paris, France, 2021; License: CC BY 4.0. Available online: https://www.iea.org/reports/india-energy-outlook-2021 (accessed on 14 September 2023).
11. Government of Iinda Ministry of New and Renewable Energy (MNRE). National Green Hydrogen Mission; 2023. Available online: https://mnre.gov.in/img/documents/uploads/file_f-1673581748609.pdf (accessed on 14 September 2023).
12. vom Scheidt, F.; Qu, J.; Staudt, P.; Mallapragada, D.S.; Weinhardt, C. Integrating hydrogen in single-price electricity systems: The effects of spatial economic signals. *Energy Policy* **2022**, *161*, 112727. [CrossRef]
13. Indian Ports Association (IPA). Green Policy for Indian Ports. 2022. Available online: http://www.ipa.nic.in/WriteReadData/Links/12370847dd7117-e73c-40eb-a5d8-de4cbc580ba0.pdf (accessed on 14 September 2023).
14. Faye, O.; Szpunar, J.; Eduok, U. A critical review on the current technologies for the generation, storage, and transportation of Hydrogen. *Int. J. Hydrogen Energy* **2022**, *47*, 13771–13802. [CrossRef]
15. IEA. *Energy Technology Perspectives 2023*; IEA: Paris, France, 2023; License: CC BY 4.0. Available online: https://www.iea.org/reports/energy-technology-perspectives-2023 (accessed on 14 November 2023).
16. International Renewable Energy Agency (IRENA). Hydrogen. IRENA, 2023. Available online: https://www.irena.org/Energy-Transition/Technology/Hydrogen (accessed on 14 November 2023).
17. Johnston, C.; Ali Khan, M.H.; Amal, R.; Daiyan, R.; MacGill, I. Shipping the sunshine: An open-source model for costing renewable hydrogen transport from Australia. *Int. J. Hydrogen Energy* **2022**, *47*, 20362–20377. [CrossRef]
18. Okada, Y.; Saito, M.; Makabe, T. Development of Dehydrogenation Catalysts for Hydrogen Storage and Transportation Systems by Organic Chemical Hydride Method. 2006. Available online: https://www.jstage.jst.go.jp/article/hess/31/2/31_8/_pdf (accessed on 14 September 2023).
19. Nishifuji, K. Rules and Safety Measures for Liquefied Hydrogen Carriers. 2019. Available online: https://www.jstage.jst.go.jp/article/jime/54/5/54_709/_pdf/-char/ja (accessed on 14 September 2023).
20. IEA. *Global Hydrogen Review 2022*; IEA: Paris, France, 2022; License: CC BY 4.0. Available online: https://www.iea.org/reports/global-hydrogen-review-2022 (accessed on 14 September 2023).
21. Yang, M.; Lam, J.S. Operational and economic evaluation of ammonia bunkering—Bunkering supply chain perspective. *Transp. Res. Part D Transp. Environ.* **2023**, *117*, 103666. [CrossRef]
22. Lan, R.; Irvine, J.T.S.; Tao, S. Ammonia and related chemicals as potential indirect hydrogen storage materials. *Int. J. Hydrogen Energy* **2012**, *37*, 1482–1494. [CrossRef]
23. Klerke, A.; Christensen, C.H.; Nørskov, J.K.; Vegge, T. Ammonia for hydrogen storage: Challenges and opportunities. *J. Mater. Chem.* **2008**, *18*, 2304. [CrossRef]
24. NITI Aayog. Harnessing Green Hydrogen. 2022. Available online: https://www.niti.gov.in/sites/default/files/2022-06/Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf (accessed on 14 September 2023).

25. Martínez de León, C.; Ríos, C.; Brey, J.J. Cost of green hydrogen: Limitations of production from a stand-alone photovoltaic system. *Int. J. Hydrogen Energy* **2023**, *48*, 11885–11898. [CrossRef]
26. The Commonwealth Scientific and Industrial Research Organisation (CSIRO). Cost Assessment of Hydrogen Production from PV and Electrolysis. 2016. Available online: https://arena.gov.au/assets/2016/05/Assessment-of-the-cost-of-hydrogen-from-PV.pdf (accessed on 14 September 2023).
27. Ministry of Finance, Government of India (MoF). Rates of Depreciation (for Income-Tax). Depreciation Rates; 2023. Available online: https://incometaxindia.gov.in/charts%20%20tables/depreciation%20rates.htm (accessed on 14 September 2023).
28. Japan Bank for International Cooperation (JBIC). Standard Financing Terms. 2023. Available online: https://www.jbic.go.jp/ja/support-menu/standard.html (accessed on 14 September 2023).
29. Ministry of Economy, Trade and Industry (METI). Fuel Ammonia Supply Cost Analysis (Interim Report). 2022. Available online: https://www.meti.go.jp/shingikai/energy_environment/nenryo_anmonia/supply_chain_tf/pdf/20220928_e0.pdf (accessed on 14 September 2023).
30. World Bank. Inflation, Consumer Prices (Annual %)—India. World Bank Open Data. 2023. Available online: https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=IN (accessed on 14 September 2023).
31. Ministry of Finance, Government of India (MoF). GST Goods and Services Rates. Goods & Service Tax, CBIC, Government of India; 2023. Available online: https://cbic-gst.gov.in/gst-goods-services-rates.html (accessed on 14 September 2023).
32. Reserve Bank of India (RBI). Reference Rate Archive. Reserve Bank of India—Reference Rate Archive. 2023. Available online: https://www.rbi.org.in/scripts/ReferenceRateArchive.aspx (accessed on 14 September 2023).
33. Department of Energy, The United States of America (DoE). DOE Hydrogen and Fuel Cells Program Record. 2020. Available online: https://www.hydrogen.energy.gov/pdfs/19009_h2_production_cost_pem_electrolysis_2019.pdf (accessed on 14 September 2023).
34. Invest India. Renewable Energy in India—Indian Power Industry Investment. In India—Indian Power Industry Investment; 2023. Available online: https://www.investindia.gov.in/sector/renewable-energy (accessed on 14 September 2023).
35. Mercom Capital Group (MCG). Gujarat Approves Lowest Tariff of ₹2.84/kwh for 500 MW of Wind Projects—MERCOM India. Mercomindia.com. 2022. Available online: https://www.mercomindia.com/gujarat-approves-lowest-tariff-500-mw-wind-projects (accessed on 14 September 2023).
36. Mercom Capital Group (MCG). Gujarat Adopts Tariff of ₹2.51/kwh for Procuring 860 MW of Solar Power—MERCOM India. Mercomindia.com. 2023. Available online: https://www.mercomindia.com/gujarat-tariff-860-mw-solar-power (accessed on 14 September 2023).
37. Paschim Gujarat Vij Company Ltd. (PGVC). Tariff Circular. 2023. Available online: https://www.pgvcl.com/consumer/tarrif/TARIFF%20CIRCULAR.pdf (accessed on 14 September 2023).
38. IRENA. *Making the Breakthrough: Green Hydrogen Policies and Technology Costs*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2021.
39. Hochman, G.; Goldman, A.S.; Felder, F.A.; Mayer, J.M.; Miller, A.J.; Holland, P.L.; Goldman, L.A.; Manocha, P.; Song, Z.; Aleti, S. Potential economic feasibility of direct electrochemical nitrogen reduction as a route to ammonia. *ACS Sustain. Chem. Eng.* **2020**, *8*, 8938–8948. [CrossRef]
40. Mitsui, O.S.K. Various Vessels "Supporting Livelihoods and Industries". Lines (MOL). 2021. Available online: https://www.mol.co.jp/iroiro_fune/images/iroiro2021.pdf (accessed on 14 September 2023).
41. Ports.com. Port of Kandla, India to Port of Tokyo, Japan Sea Route and Distance. Ports.com. 2023. Available online: http://ports.com/sea-route/port-of-mundra,india/port-of-tokyo,japan/#/?a=4018&b=0&c=Port%20of%20Kandla,%20India&d=Port%20of%20Tokyo,%20Japan (accessed on 14 September 2023).
42. Ports.com. Port of Chennai, India to Port of Tokyo, Japan Sea Route and Distance. Ports.com. 2023. Available online: http://ports.com/sea-route/port-of-chennai,india/port-of-tokyo,japan/ (accessed on 14 September 2023).
43. Rivarolo, M.; Riveros-Godoy, G.; Magistri, L.; Massardo, A.F. Clean hydrogen and ammonia synthesis in Paraguay from the Itaipu 14 GW hydroelectric plant. *ChemEngineering* **2019**, *3*, 87. [CrossRef]
44. The Institute of Energy Economics, Japan (IEEJ). Current Status of Ammonia Supply/Demand and Import Prices. 2015. Available online: https://eneken.ieej.or.jp/data/6317.pdf (accessed on 14 September 2023).
45. The Economic Times. Solar Power Tariff Dips to All-Time Low of rs 1.99 per Unit: Report. 2020. Available online: https://economictimes.indiatimes.com/industry/energy/power/solar-power-tariff-dips-to-all-time-low-of-rs-1-99/unit/articleshow/79839682.cms (accessed on 14 September 2023).
46. Government of Iinda Ministry of New and Renewable Energy (MNRE). Scheme Guidelines for Implementation of "Strategic Interventions for Green Hydrogen Transition (SIGHT) Programme—Component 1: Incentive Scheme for Electrolyser Maufacturing" of the National Green Hydrogen Mission. 2023. Available online: https://mnre.gov.in/img/documents/uploads/file_f-1687964057675.pdf (accessed on 14 September 2023).
47. CNBC TV18. India Launches Schemes Worth Rs 17,490 Crore to Drive Electrolyser, Green Hydrogen Manufacturing. cnbctv18.com. 2023. Available online: https://www.cnbctv18.com/business/india-launches-schemes-worth-rs-17490-crore-to-drive-electrolyser-green-hydrogen-manufacturing-17080111.htm (accessed on 14 September 2023).
48. U.S. Department of Energy (DoE). Hydrogen Shot. Energy.gov; 2021. Available online: https://www.energy.gov/eere/fuelcells/hydrogen-shot (accessed on 14 September 2023).

49. The White House of the U.S. (WHUS). Building a Clean Energy Economy—The White House. 2023. Available online: https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf (accessed on 14 September 2023).
50. EY India. How does India Inc. View Its Cost of Capital? EY US—Home. 26 May 2021. Available online: https://www.ey.com/en_in/strategy-transactions/how-does-india-inc-view-its-cost-of-capital (accessed on 14 September 2023).
51. Policy Research Institute, Ministry of Finance, Japan. Challenges of the Indian Economy in Recent Years: Trade Structure and Non-Performing Loan Problem Perspectives. 2021. Available online: https://www.mof.go.jp/pri/publication/ (accessed on 14 September 2023).
52. The Japan Research Institute, Limited. Increased Interest in Indian Business by Japanese Companies. 2023. Available online: https://www.jri.co.jp/page.jsp?id=104616 (accessed on 14 September 2023).
53. Japan Machinery Center for Trade and Investment (JMC). Problems and Requests in India. 2022. Available online: https://www.jmcti.org/mondai/pdf/chosakekka2022.pdf (accessed on 14 September 2023).
54. Ministry of Economy, Trade and Industry (METI). Joint Crediting Mechanism. JCM. 2023. Available online: https://www.meti.go.jp/policy/energy_environment/global_warming/jcm/index.html#:~:text=%E4%BA%8C%E5%9B%BD%E9%96%93%E3%82%AF%E3%83%AC%E3%82%B8%E3%83%83%E3%83%88%E5%88%B6%E5%BA%A6%EF%BC%88Joint%20Crediting%20Mechanism%3B%20JCM%EF%BC%892023,%E3%81%AB%E6%B4%BB%E7%94%A8%E3%81%99%E3%82%8B%E5%88%B6%E5%BA%A6%E3%81%A7%E3%81%99%E3%80%82 (accessed on 14 September 2023).
55. Gold Standard. Carbon Pricing: What Is a Carbon Credit Worth? CARBON PRICING: What Is a Carbon Credit Worth? | The Gold Standard. 2023. Available online: https://www.goldstandard.org/blog-item/carbon-pricing-what-carbon-credit-worth (accessed on 14 September 2023).
56. Ministry of the Environment of Japan. Aid Memoire on the Joint Crediting Mechanism between The Ministry of the Environment of Japan and Ministry of Environment, Forest and Climate Change of the Republic of India. 2023. Available online: https://www.env.go.jp/content/000121764.pdf (accessed on 14 September 2023).
57. New Energy and Industrial Technology Development Organization (NEDO). Project to Promote the Diffusion of Low-Carbon Technologies Utilizing the Bilateral Crediting Mechanism (JCM), etc. NEDO, 2023. Available online: https://www.nedo.go.jp/activities/ZZJP_100022.html (accessed on 14 September 2023).
58. Ministry of Economy Trade and Industry (METI). How to Proceed with the Hydrogen and Fuel Cell Strategic Council. 2023. Available online: https://www.meti.go.jp/shingikai/energy_environment/ (accessed on 14 September 2023).
59. Research Institute of Economy, Trade and Industry. Rapidly Growing Geopolitical Risks of Oil Transportation Japan's Energy Security Must Be Reexamined from the Ground Up. RIETI, 2020. Available online: https://www.rieti.go.jp/jp/papers/contribution/fuji-kazuhiko/179.html (accessed on 14 September 2023).
60. Kawasaki Heavy Industry (KHI). KHI Completes Technical Development of Cargo Tanks for Large Liquefied Hydrogen Carriers: Press Release. 2023. Available online: https://www.khi.co.jp/pressrelease/detail/20230606_1.html (accessed on 14 November 2023).
61. Zhang, T.; Uratani, J.; Huang, Y.; Xu, L.; Griffiths, S.; Ding, Y. Hydrogen liquefaction and storage: Recent progress and Perspectives. *Renew. Sustain. Energy Rev.* **2023**, *176*, 113204. [CrossRef]
62. Berstad, D.; Gardarsdottir, S.; Roussanaly, S.; Voldsund, M.; Ishimoto, Y.; Nekså, P. Liquid hydrogen as Prospective Energy Carrier: A brief review and discussion of underlying assumptions applied in value chain analysis. *Renew. Sustain. Energy Rev.* **2022**, *154*, 111772. [CrossRef]
63. Bristowe, G.; Smallbone, A. The key techno-economic and manufacturing drivers for reducing the cost of power-to-gas and a hydrogen-enabled energy system. *Hydrogen* **2021**, *2*, 273–300. [CrossRef]